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# From Research to Public Policy:

# Progress in Scientific and Public Understanding of Acid Precipitation and Its Biological Effects

by

Ellis B. Cowling
School of Forest Resources
North Carolina State University
Raleigh, NC 27650

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EPA Project Officer
R. W. Wilhour

Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Corvallis, OR 97333

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16. ABSTRACT

Wisdom in the development of public policy requires objective assessments of fact. Scientific understanding of acid precipitation and its biological consequences has increased substantially in recent years but needs to be expanded still further. At present much more is known about the nature and extent of effects of acid precipitation in aquatic than in terrestrial ecosystems.

Increasing acidity of precipitation has been shown to induce extinction of fish & other major changes in the health and productivity of many different types of organisms in poorly buffered lakes in large parts of Europe and eastern North America. thus, available knowledge is adequate to begin the process of formulating public policies to protect sensitive aquatic ecosystems from these injurious influences.

By contrast, recent research on terrestrial ecosystems has shown that 1) atmospheric deposition contains both beneficial nutrients and injurious substances; 2) terrestrial plants, animals, and ecosystems vary greatly in susceptibility, tolerance, and adaptability to changes in atmospheric deposition; 3) injury is most likely when rapid changes in the chemical climate coincide with a vulnerable life form or life stage; 4) simulated acid rain can cause leaching of nutrients from foliage and from soil, and both direct and indirect injury to terrestrial vegetation. With rare exceptions, however, economic damage to forest trees and agricultural crops by naturally occurring acid rain has not been demonstrated to date. More research is needed before policies can be formulated.

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## ABSTRACT

Wisdom in the development of public policy requires objective assessments of fact. Scientific understanding of acid precipitation and its biological consequences has increased substantially in recent years but needs to be expanded still further. At present, much more is known about the nature and extent of effects of acid precipitation in aquatic than in terrestrial ecosystems.

Increasing acidity of precipitaton has been shown to induce extinction of fish and other major changes in the health and productivity of many different types of organisms in poorly buffered lakes in large parts of Europe and eastern North America. Thus, available knowledge is adequate to begin the process of formulating public policies to protect sensitive aquatic ecosystems from these injurious influences.

By contrast, recent research on terrestrial ecosystems has shown that (1) atmospheric deposition contains both beneficial nutrients and injurious substances; (2) terrestrial plants, animals, and ecosystems vary greatly in susceptibility, tolerance, and adaptability to changes in atmospheric deposition; (3) injury is most likely when rapid changes in the chemical climate coincide with a vulnerable life form or life stage; (4) simulated acid rain can cause leaching of nutrients from foliage and from soil, and both direct and indirect injury to terrestrial vegetation. With rare exceptions, however, economic damage to forest trees and agricultural crops by naturally occurring acid rain has not been demonstrated to date. Thus, much more research is needed before wise public policies can be formulated with regard to the biological consequences of acid precipitation in terrestrial ecosystems.


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Some years ago the terms "acid precipitation" and "acid rain" were bits of esoteric jargon used almost exclusively by scientists in certain specialized fields of ecology and atmospheric chemistry. Recently, these terms have become worrisome household words and objects of both national and international debate. How did this transition come about? Who was responsible? Why did it take so long for acid precipitation to be recognized as an important ecological problem? Do we know enough now to try to do something about acid rain?

This brief paper is an attempt to answer some of these questions. Our approach will be to review various steps in the transformation of the concept of acid precipitation from the domain of scientific curiosity to the domain of public concern and debate about regulatory policy (See Table 1). The story is a classic one. It illustrates how much man needs to learn about the complex physical, chemical, and biological world in which we live, and work, and exert so many influences -- both intended and unintended. It also illustrates the need for much more effective and timely communication -- both among investigators in various branches of science, and between scientists and officials of government, leaders of industry, and the public at large.

In Table 1, an historical resume of progress in understanding the phenomenon and biological effects of acid precipitation is presented to show the various stages in evolution of scientific understanding about acid precipitation and its ecological effects. Names of major contributors, the country in which the work was achieved, and the principal contribution to science are presented in chronological order.

Table 1. An Historical Resume of Progress in the Scientific Understanding of Acid Precipitation and Its Consequences.

| Approximate Date | Investigator & Country | Principal Scientific Contribution |
|---|---|---|
| 1671 | Hooke, England | Reported uptake of nutrients from the atmosphere by feeding through foliar organs. |
| 1911 | Crowther & Ruston, England | Demonstrated gradients in acidity of precipitation decreasing from the center of Leeds, England and associated this gradient with the combustion of coal. |
| 1923 | Sørenson, Denmark | Developed the pH scale to describe the acidity of aqueous solutions. |
| 1926 | Dahl, Norway | Demonstrated the relationship between the acidity of surface waters and production of trout. |
| 1939 | Bottini, Italy | Detected hydrocholoric acid in precipitation near the volcano on Mount Vesuvius thus establishing that there are natural sources of strong acids in precipitation. |
| 1940 | Snekvik, Norway | Made the first surveys of fish populations and water chemistry in Norway. |
| 1942 | Conway, Ireland | Completed the first detailed studies of precipitation chemistry. |
| 1948 | Egnér, Sweden | Established the first large-scale precipitation chemistry network in Europe. |
| 1950-55 | Rossby & Eriksson, Sweden | Enunciated a general theory of biogeochemical circulation of matter through the atmosphere. Developed the European Air Chemistry Network which has provided a continuing record of precipitation chemistry in Europe for 3 decades. |
| 1953-55 | Various investigators in several countries | Simultaneously investigated precipitation chemistry data for evidence of atmospheric acidity -- Barrett and Brodin, Sweden; Parker and Gorham, England; Houghton and Jordan et al., USA |
| 1957 | Europe, USSR and U.S.A. | A one-year study of precipitation chemistry in Europe, the USSR, and the USA was made during the International Geophysical Year. |

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| 1954-61 | Gorham, England | Demonstrated that hydrochloric acid from combustion of coal rich in chlorine predominated in urban precipitation whereas sulfuric acid predominated in rural precipitation.<br><br>Demonstrated that acidity in precipitation markedly influenced geological weathering processes and the chemistry of lake waters, bog waters, and soils.<br><br>Established that acidity in precipitation affects the alkalinity and buffering capacity of lake and bog waters.<br><br>Established a correlation between atmospheric acidity and the incidence of bronchitis in man. |
| 1959 | Dannevig, Norway | Recognized the relationship between acid precipitation, acidity in surface waters, and disappearance of fish. |
| 1961-63 | Gordon & Gorham, Canada | Established that fumigation by sulfur dioxide and resultant acid rain contributed to the deterioration of vegetation, soils, and lake-water quality near metal smelters. |
| 1960-67 | Lodge & Lazarus et al, USA | Established the first continent-wide precipitation chemistry network in North America. Showed that precipitation is generally acidic east but alkaline west of the Mississippi River. |
| 1967-68 | Odén, Sweden | Outlined the changing acidity of precipitation as a regional and temporal problem in Europe.<br><br>Used trajectory analysis of air masses to demonstrate that acidity in precipitation in Scandinavia could be attributed to emissions of sulfur in England and central Europe.<br><br>Demonstrated temporal trends in acidity and major cations and anions in precipitation in various parts of Europe.<br><br>Demonstrated the increasing acidity of Scandinavian rivers.<br><br>Described biological uptake and ion-exchange processes by which natural acidification would be accelerated by atmospheric deposition of ammonia and other cations.<br><br>Postulated that acid precipitation would lead to displacement of nutrient cations, reduction in nitrogen fixation, and release of heavy metals (specifically Hg) which would damage surface waters and ground waters. |

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| | | Postulated acidity in precipitation as a probable cause of decline in fish populations, impoverishment of forest soils, decreased forest growth, increased disease in plants, and accelerated corrosion and other damage to materials. |
| 1971 | Odén, Ahl, Pergholm, Sweden | Discovered that soluble pollutants in snow accumulate in the snow pak and are released almost totally with the first meltwater in spring. |
| 1971-72 | Bolin et al, Sweden | Drafted Sweden's Case Study for the United Nations Conference on the Human Environment "Air Pollution Across National Boundaries: The Impact on the Environment of Sulfur in Air and Precipitation". |
| 1971-79 | Likens, et al and Cowling et al, USA | Initiated studies of the chemistry and biological consequences of acid precipitation and encouraged development of a permanent precipitation chemistry network in the United States. |
| 1972 | Norwegian Government | Initiated the SNSF Project: "Acid Precipitation: Effects on Forests and Fish". |
| 1972 | Overrein, Norway | Demonstrated accelerated loss of calcium and other cations from soils receiving acid precipitation. |
| 1972 | Likens et al, USA | Discussed the threat of acid precipitation to aquatic and terrestrial ecosystems in North America. Likens apparently introduced the popular term "acid rain" into English. |
| | | Established that nitric acid resulting from atmospheric transformation of $NO_x$ contributes to the acidity of precipitation in the eastern United States. |
| 1972 | Almer, Sweden | Demonstrated the effects of changing acidity on fish populations in Sweden. |
| 1972 | Beamish & Harvey Canada | Reported decline in fish populations due to acidification of lakes in Canada. |
| 1974 | Cogbill & Likens, USA | Published maps showing changes in acidity of precipitation in North America between 1955-56 and 1972-73. |
| 1974 | Grahn et al, Sweden | Discovered that Sphagnum (peat moss) invades acidified lakes and streams inducing a self-accelerating oligotrophication of the water body. |

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| 1974-76 | Shriner, USA | Demonstrated that simulated rain acidified with sulfuric acid can induce accelerated erosion of epicuticular waxes on leaves, inhibit nodulation of leguminous plants, and alter host-pathogen interactions of plants. |
| 1975 | Dickson, Sweden<br>Schofield, USA | Published results of lake surveys in southern Sweden and the Adirondack Mountains of New York showing the relationship between fish populations and acidity of lakes. |
| 1976 | Galloway and Likens, USA:<br>Granat, Sweden<br>Whelpdale, Canada | Developed standardized protocols for precipitation collectors and collection techniques. |
| 1978-79 | Liljestrand and Morgan, USA;<br>Grant and Lewis, USA | First detected acid precipitation in western North America. |
| 1979 | Cronan and Schofield, USA<br>Dickson, Sweden | Discovered that aluminum ions are leached by acid precipitation from soils into streams and lakes in concentrations toxic to fish. |

Major International Conferences Documenting Further Progress

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| 1975-76 | Dochinger & Seliga, USA | U.S. Forest Service sponsored the First International Symposium on Acid Precipitation and the Forest Ecosystem at The Ohio State University, Columbus, Ohio. |
| 1976 | Overrein et al, Norway | SNSF Project and the Norwegian Ministry of the Environment sponsored the International Conference on Effects of Acid Precipitation, Telemark, Norway. |
| 1978 | Hutchinson, Canada | NATO Sponsored an Advanced Research Institute on Ecological Effects of Acid Precipitation in Toronto, Canada. |
| 1978 | Howells, England | The Electric Power Research Institute (USA) and the Central Electricity Generating Board (Great Britain) sponsored an international symposium on Ecological Effects of Acid Precipitation. |
| 1978 | Hendrey et al, USA | U.S. Environmental Protection Agency sponsored an International Workshop on Limnological Aspects of Acid Precipitation, Sagamore Lake, New York. |
| 1979 | Shriner, USA | The Oak Ridge National Laboratory sponsored a symposium on the Potential Environmental and Health Effects of Sulfur Deposition, Gatlinburg, Tennessee. |

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| 1979 | Agle, USA, and Turnbull, Canada | A group of Canadian and United States environmental protection organizations sponsored the Action Seminar on Acid Precipitation, Toronto, Canada. |
| 1980 | Overrein et al, Norway | The SNSF project will sponsor an International Conference on Ecological Impacts of Acid Precipitation, Sandefjord, Norway. |

## Early Awareness of Acid Precipitation

The concept of acidity is as old as chemistry itself. In fact, acids were familiar tools in the hands of alchemists in the middle ages. The concept of acidity in soils also is quite old. Liming of agricultural land to neutralize excess acidity began in the 17th century. But the idea and importance of acidity in precipitation is a very recent development. It had its origins in three seemingly unrelated fields of science: limnology (the study of lakes), agriculture, and atmospheric chemistry. Let us look at the contribution of each field of science in turn.

### Progress in Limnology

The relationship between rain or snow, and the water in streams and lakes was obvious even to prehistoric man. But the relationship between changes in the chemistry of rain and snow, and changes in the chemistry of lake waters remained obscure until the middle of the 20th century. Crowther and Ruston (1911) apparently were the first to establish a relationship between increased combustion of coal and the chemical substances scrubbed out of the air by precipitation. They were mistaken, however, in attributing the acidity of precipitation near the industrial city of Leeds in England to the sulfur content, rather than the high chlorine content of English coal.

In a long series of papers beginning in 1955, Eville Gorham (1955, 1958a, 1958b, 1961, 1965), now Professor of Ecology of the University of Minnesota, built the major foundations for our present understanding of the causes of acidity in precipitation and its impact on aquatic ecosystems. On the basis of research both in England and in Canada, Gorham and his colleagues demonstrated the following principles:

1) Much of the acidity of precipitation in industrial regions can be attributed to atmospheric emissions produced during combustion of fossil fuels;

2) Progressive loss in alkalinity of lake waters and increase in the acidity of bog waters can be traced to atmospheric deposition of acidic substances in precipitation;

3) Much of the free acidity in soils receiving acid precipitation is due to sulfuric acid;

4) The incidence of bronchitis in man can be correlated with the acidity precipitation; and

5) Fumigation with sulfur dioxide and resultant acid rain contribute to the deterioration of vegetation, soils, and lake-water quality around metal smelters (Gordon and Gorham, 1963).

Thus, by the mid 1950's and early 1960's, Gorham had established a major part of our present understanding of the sources and the limnological and ecological significance of acidity in precipitation. But these pioneering researches were met by a thundering silence from both the scientific community and the public at large. This lack of recognition may have resulted in part because Gorham published his highly interdisciplinary researches in a diverse array of respected scientific journals. Whatever the reason, this lack of recognition resulted in at least a 10-year lag in both scientific and public awareness of acid precipitation and its ecological significance.

Progress in the Agricultural Sciences

The importance of the atmosphere as a source of nutrients for the growth and development of plants was first recognized by Robert Hooke in 1671. Early experiments at the Rothamsted Experiment Station in England also demonstrated the relationship between nutrients in air and the growth of various crop plants. In the mid 1940's an imaginative Swedish soil scientist, Hans Egnér, systematized investigations on the fertilization of crops by atmospheric sources of nutrients. Working from his laboratory at the Agricultural College near Uppsala, Egnér created the first network for the collection and chemical analysis of precipitation. A large number of sampling buckets were set out at experimental farms all over Sweden and the major chemical constituents in what we now call bulk deposition (rain, snow and dust fall) were measured on a regular monthly basis. The acidity of precipitation was one of several chemical parameters that were measured. This network, initiated by Egnér in 1948, was gradually spread by other agricultural scientists -- first to Norway, Denmark, and Finland and later to most of western and central Europe. This network provided the first large-scale and long-term data on the changing chemistry of precipitation and its importance for agriculture and forestry (Emanuelsson et al, 1954). In 1956, the International Meteorological Institute in Stockholm assumed responsibility for further coordination of the European Air Chemistry Network. In 1957, as part of the International Geophysical Year, the European Network spread eastward to include Poland and much of the Soviet Union. In marked contrast to monitoring efforts elsewhere in the world, the original European Network has remained in continuing operation with more than 100 collection stations for nearly three decades!

Progress in the Atmospheric Sciences

Under the imaginative leadership of Carl Gustav Rossby and Erik Eriksson, the science of atmospheric chemistry began in Sweden and later spread across Europe and finally to North America. Rossby and Eriksson were convinced that atmospheric processes were efficient mechanisms for the long-distance as well as the short-distance dispersal of all sorts of substances. The data from Egnér's precipitation chemistry network provided the means to test various hypotheses about the trajectories of air masses, turbulent dispersal processes, and atmospheric scavenging and deposition processes.

The transport and deposition of water by atmospheric processes was well known since the earliest observations of evaporation, wind and cloud movement, and of rain and snow. But the notion that atmospheric transport, and deposition processes were major means for dispersal and chemical transformation of many other substances was still only a working hypothesis in the

early 1950's. Rossby and Eriksson championed these then novel ideas and initiated various experimental tests of their hypotheses. Data from the European Air Chemistry Network provided a very powerful tool for these studies. Rossby and Eriksson also sponsored a series of European conferences on atmospheric chemistry and dispersal processes. These conferences attracted the interest of scientists in many aspects of biology and meteorology (Eriksson, 1952; 1959; 1960).

Integration of Limnological, Agricultural, and Atmospheric Chemical Studies

The first major integration of knowledge about acid precipitation in these three fields of science was achieved by Svante Odén, a soil scientist at the Agricultural College near Uppsala in Sweden. As a young colleague of Egnér, Rossby, and Eriksson, Odén started a Scandinavian network for surface water chemistry in 1961. When data from this network were combined with those from the European Air Chemistry Network, a series of general trends and relationships began to emerge and were published by Odén in two different media -- in Stockholm's prestigious newspaper Dagens Nyheter (Odén, 1967) and in an Ecology Committee Bulletin (Odén, 1968). The newspaper story outlining Odén's ideas captured the attention of the press who began the process of public education about acid precipitation in Europe. The Ecology Committee Bulletin had a similarly stimulating influence on scientific interest in both the phenomenon and the ecological effects of acid precipitation. Suddenly, limnological, agricultural, and atmospheric scientists began talking to each other about Odén's unconventional ideas and the general theory of atmospheric influences which he enunciated. His analyses of air-mass trajectories clearly showed that acid precipitation was a large-scale regional phenomenon in much of Europe, that both precipitation and surface waters were becoming more acidic, and that long-distance (100-2000 km) transport of both sulfur- and nitrogen-containing air pollutants was occurring among the various nations of Europe. Odén also enunciated a series of hypotheses about the probable ecological consequences of acid precipitation -- decline of fish populations, decreased forest growth, increased plant diseases, and accelerated damage to materials. These conclusions and hypotheses led to a veritable storm of scientific and public concern about acid precipitation. The Swedish government responded to growing public and scientific interest by initiating an inquiry which culminated in Sweden's Case Study for the United Nations Conference on the Human Environment -- "Air Pollution Across National Boundaries: The Impact of Sulfur in Air and Precipitation" (Bolin et al, 1972).

The major ideas in both the Ecology Committee Bulletin and the Swedish Case Study were much debated all over Europe. Two major scientific initiatives followed in short order. The first occurred in 1972 when the Norwegian government established the so-called SNSF Project -- a special interagency research project called "Acid Precipitation: Effects on Forests and Fish" with an annual budget of about 10,000,000 Norwegian Kroner (US $2,000,000). This huge project had two comprehensive goals:

1) To establish as precisely as possible, the effects of acid precipitation on forests and freshwater fish; and

2) To investigate the effects of air pollutants on soils, vegetation, and water to the extent required to support the primary objective.

The second major initiative was the so-called OECD Study which provided quantitative data on the long distance transport and deposition of atmospheric sulfur in both eastern and western Europe. The results, which were published in 1977 by the Organization for Economic Cooperation and Development (OECD, 1977) confirmed many of the ideas presented in the Ecology Committee Bulletin and the Swedish Case Study regarding the long-distance international exchange of sulfur dioxide and acid precipitation among the nations of Europe.

## Scientific and Public Awareness in North America

Concern about acid precipitaton and its ecological effects in North America developed first in Canada and then later in the United States. Initial interests were focused on the effects of sulfur dioxide fumigation and associated acid precipitation near metal smelting operations, especially those near Sudbury, Ontario -- the largest point source of sulfur in the world. During the early 1970's, interest spread to other parts of Canada as declining fish populations were discovered in more and more lakes remote from local sources of atmospheric sulfur in southern Ontario, and Nova Scotia. The first national monitoring program for precipitation chemistry in Canada was initiated by the Canadian Department of the Environment in 1975.

The first detailed studies of precipitation chemistry in the United States were made by Junge and various collaborators during the 1950's (Junge and Werby, 1958). The first regional monitoring of precipitation chemistry was done by a group of State Agricultural Experiment Station scientists from 1953-55 (Jordan et al, 1959). The first national monitoring program was established by the National Center for Atmospheric Research in 1960 (Lodge et al, 1968); but as has been the case in all such studies in the United States, these early programs were redirected and/or terminated so that no continuing records of long-term trends in precipitation chemistry are available.

Scientific and public interest in acid precipitation and its ecological consequences were stimulated by Forston Ahl and Svante Odén at the 19th International Limnological Congress in Winnipeg, Manitoba, in 1974 and by Odén in a series of 14 lectures at various institutions in the United States during the fall of 1971. Further stimulus was provided by a series of publications by Gene Likens, Charles Cogbill, James Galloway, and Carl Schofield and others (Likens et al, 1972; Likens, 1976; Cogbill and Likens, 1977; Schofield, 1976; Galloway and Likens, 1976). Studies of various biological effects of acid precipitation were initiated at Cornell, North Carolina State and other universities. David Shriner's (1947) dissertation demonstrated both direct injury to vegetation and various indirect effects through pathogens and parasites. Carl Schofield's (1976) research on extinction of fish populations in the Adirondack Mountains was especially alarming.

Growing awareness of important impacts of acid precipitation on fish populations and potential effects on forest led the U.S. Forest Service to sponsor the First International Symposium on Acid Precipitation and the Forest Ecosystem in Ohio in May 1975. The Proceedings of this Symposium and the associated Workshop Report were published by Dochinger and Seliga (1976a, 1976b). At Congressional hearings in July 1975, Cowling (1976) testified on the inadequacy of research in the United States on acid precipitation. Specifically, the lack of a coordinated

program of research on ecological effects and lack of a stable monitoring network were recognized as primary causes of our profound ignorance of acid precipitation. In the spring of 1976, however, a cadre of many scientists in various institutions and agencies throughout the United States began the process of creating the National Atmospheric Deposition Program (NADP) to meet these two critical needs (Kennedy, 1977; Galloway and Cowling, 1978).

In the fall of 1977, the President's Council on Environmental Quality contracted with the NADP for the drafting of "A National Program for Assessing the Problem of Atmospheric Deposition (Acid Rain)". This publication (Galloway et al, 1978) provided the basis for a Presidential Initiative on Acid Precipitation which President Carter announced on August 2, 1979 in his Second Environmental Message (Carter, 1979). This initiative calls for a 10-year long, $10,000,000 per year program of research on the causes and consequences of acid precipitation. A standing Acid Rain Coordinating Committee was established by the President to plan and manage the program. The Committee consists of policy-level representatives from the Department of Agriculture, Department of Interior, Department of Energy, Department of Commerce, Department of State, the Environmental Protection Agency, the National Science Foundation, the Council on Environmental Quality, and the Office of Science and Technology Policy. Leadership for the Committee is provided by co-chairmen Rupert Cutler of the Department of Agriculture and Stephen Gage of the Environmental Protection Agency with the Council on Environmental Quality serving as Executive Secretary.

## The Present Status of Knowledge Concerning Acid Precipitation

During the summer of 1979 a Cooperative Agreement was established between the U.S. Environmental Protection Agency, the National Atmospheric Deposition Program, and North Carolina State University for the management and coordination of research on the Effects of Acid Precipitation on Aquatic and Terrestrial Ecosystems. One of the major responsibilities specified in this Agreement is synthesis and integration of knowledge about acid precipitation and its ecological effects. Accordingly, an effort was made to summarize in a few statements of fact, the present status of knowledge in this area of science. A portion of this Status Report is presented in Table 2. These summary statements are providing a part of the background upon which scientists in various institutions and organizations in the United States and Canada will continue to build a scientific foundation for understanding the phenomenon of acid precipitation and its important ecological effects.

## The Present Status of Discussion About Public Policy

In light of the statements of fact contained in Table 2, the following general judgments about public policy appear to be appropriate:

1) As of December 1979, the effects of acid precipitation and associated metal-ion toxicity on aquatic ecosystems are sufficiently well understood that preliminary formulation of regulatory and ameliorative policies can be initiated now.

2) As of this same month, however, potential effects on terrestrial organisms are still too poorly understood to justify consideration of regulatory policies at this time.

Table 2. A Status Report on Acid Precipitation

The summary statements listed below describe the general status of knowledge about acid precipitation and its ecological consequences as of December 1979.

Acid precipitaton (rain, snow, hail, dew, frost) is occurring in large regions of the eastern United States and Canada, Europe and Japan. It has also been reported in certain urban and rural areas in the western United States and may occur in other regions of the world.

This widespread deposition of acidic precipitation and dry deposition results in large part from increased total emissions of oxides of sulfur and nitrogen. These substances are transformed in the atmosphere to sulfuric and nitric acids, transported over great distances, and deposited on vegetation, soils, surface water and materials.

The ratio of sulfuric to nitric acids in precipitation varies from time to time and from place to place. In much of the eastern United States the average annual ratio of sulfuric to nitric acids is currently about 2:1; but nitric acid is becoming progressively more important relative to sulfuric acid.

Tall stacks at power plants decrease groundlevel concentrations of $SO_2$ and $NO_x$ but simultaneously increase the geographical area of acid deposition. Removal of alkaline particulate matter from stack emissions also increases the acidifying effect of atmospheric deposition into ecosystems.

Analyses of air-mass movements and chemical transformation in the atmosphere indicate that acid precipitation in one state or region of the United States or Canada results in part from emissions into the atmosphere in other states or regions often many hundreds of kilometers from the original source of the emissions.

Contemporary precipitation is acidified by transformation products of both natural and man-made emissions of gases, aerosols and particulate matter. Major anthropogenic sources include combustion of fossil fuels (especially coal and oil), certain industrial processes (especially smelting of ores), exhausts from internal combustion engines, and nitrogen fertilization of agricultural and forest land.

Acidity in precipitation is a reflection of the balance between the major cations and anions in precipitation. Thus, to understand the acidity of precipitation, it is essential to measure all the major anions and cations in precipitation (especially $H^+$, $NH_4^+$, $NO_3^-$, and $SO_4^=$, but also including $K^+$, $Na^+$, $Ca^+$, $Mg^+$, $Cl^-$, $CO_3^=$, $SO_3^=$, and $PO_4^=$).

All of the major anions and cations transferred into ecosystems when it is raining or snowing (wet deposition) also are contained in the gases, aerosols, and particulate matter that are transferred from the atmosphere into ecosystems when it is not raining or snowing (dry deposition). Thus, in a chemical mass balance sense, it is both impossible and unrealistic to distinguish the biological effects of "acid precipitation" (wet deposition) from the biological effects of dry deposition.

In addition to the direct deposition of acidic substances into ecosystems as wet and dry deposition, some ionic materials (notably various complexes of ammonium and sulfate ions) although chemically neutral (or nearly so) are acidifying in their effects when they are taken up by plants and animals. Thus, the concept of "acidifying precipitation" must be added to the concept of "acid precipitation".

The potentially injurious substances in dry and wet deposition include not only acidic substances but also certain organic substances as well as various other inorganic substances or heavy metals such as Mn, Zn, Cu, Fe, Mo, B, F, Br, Al, Pb, I, Ni, Cd, V, Hg, As, etc.

The underlined elements listed above are essential micro-nutrients needed by plants in small amounts. At higher concentrations, however, each of these same elements (and all the others) can be toxic to plants and animals. Furthermore. the acidity of precipitation can affect the solubility, mobility, and toxicity of certain of these elements. These substances can affect the following: 1) the foliage and roots of plants; 2) animals or microorganisms that may ingest or decompose these plants; 3) animals (including man) which may drink water containing these elements; and 4) animals (especially fish and other aquatic organisms) that live in chemical equilibrium with waters containing these substances.

Acid precipitation is only one special feature of the general phenomenon of atmospheric deposition.

Damage or injury to aquatic or terrestrial organisms is most likely when a particularly sensitive life form or life stage developing in poorly buffered waters or soils coincides (in time and/or space) with major episodic inputs of acid precipitation or other injurious substances.

Acids and other soluble substances contained in polluted snow are released as polluted meltwater during warm periods in winter or in early spring. The resulting release of pollutants can cause major and rapid changes in the acidity and other chemical properties of stream and lake waters. Fish kills are a dramatic consequence of such episodic inputs into aquatic ecosystems.

Acid precipitation titrates the acidity/alkalinity of lake and stream waters from conditions that are favourable for fish and other aquatic organisms to conditions that inhibit reproduction and/or recruitment of populations of fish and fish-food organisms.

At pH's between 6.0 and 5.0, reproduction of many species of aquatic organisms is inhibited.

At pH's below 5.0, populations of many fresh-water fish will go to extinction.

Interference with normal reproductive processes in fish populations is induced not only by acidity itself but also by increased concentrations of certain cations - notably aluminum - in acidified lake and stream waters.

As of 1979, hundreds of lakes in the Adirondack region of New York State, certain lakes in northern Minnesota, and many hundreds of lakes in various parts of southern Ontario and Quebec were showing acid stress in the form of diminished populations or extinction of fish populations. Lakes and streams in other regions of the United States and Canada also are vulnerable to stress by acid precipitation.

The chemical composition of lake, stream, and ground waters is determined in part by the chemical composition of precipitation and dry deposition. The chemical composition of precipitation is modified by chemical and biological weathering and exchange processes as precipitation 1) washes over vegetation, 2) percolates through the soil, and 3) interacts with the underlying bedrock of the drainage basin in which the precipitation occurs.

Acid precipitation increases the solubility and mobility of many cations in soil. This increases the concentration of toxic metal cations including Al, Mn, and Zn in the soil solution. It also increases the leaching of nutrient cations including K, Ca, Mg, etc. These toxic and nutrient ions are transferred from soils into surface and ground waters.

Terrestrial and aquatic ecosystems are so intimately linked that it is both impossible and unrealistic to consider the effects of acid precipitation in aquatic ecosystems without considering its effects on terrestrial vegetation, soils, and the geology of the drainage basin.

Substantial damage to crops in certain regions of the United States is caused by the dry deposition of toxic gases, aerosols, and particulate matter. Sulfur dioxide, ozone, oxides of nitrogen, fluoride, and hydrogen chloride cause serious damage to crops that must be considered together with the possible effects of acid deposition.

Direct and indirect damage to crops and forests have been reported in laboratory, greenhouse, and field experiments in which synthetic rain equivalent (in chemical composition and rate of deposition) to natural rains has been applied. The biological effects include :

- Induction of necrotic lesions on foliage;
- Loss of nutrients due to leaching from foliar organs;
- Predisposition of plants to infection by bacterial and fungal pathogens;
- Accelerated erosion of waxes on leaf surfaces;
- Inhibition of nodulation of legumes leading to decreased nitrogen fixation by symbiotic bacteria;
- Reduced rates of decomposition of leaf litter leading to decreased mineralization of organically-bound nutrients, and
- Reduced yield of marketable crops.

The consequences of acid inputs to soils vary greatly, depending upon the rates and recent history of atmospheric acid inputs, the character of the vegetation, natural rates of acid formation in the soil, and the physical-chemical properties of the soil parent material.

Soil acidification increases leachings of exchangeable plant nutrients such as Ca, Mg, K, Fe, and Mc, and increases the rate of weathering of most minerals. It also makes $PO_4$ less available to plants.

Acidification decreases the rate of many soil microbiological processes such as N fixation and breakdown of organic matter. VArious processes important in nutrient cycling, and critical in most ecosystems, are known to be inhibited by lowering soil pH. Included are: nitrogen fixation by Rizobium bacterial on legumes and by Azotobacter; mineralization of nitrogen from forest litter; nitrification of ammonium compounds; and overall decay rates of forest floor materials.

Acidification of soils reduces the availability of phosphorus to plants and increases the solubility of other elements, some of which are phytotoxic.

Soils differ by orders of magnitude in their susceptibility to acidification. Calcareous soils are unlike to be damaged by the acid input, but may be affected by metal depositon. Soils with very low cation exchange capacity are very susceptible to increased acidification.

Large quantities of hydrogen ions are added to soils as acid precipitation and as a result of soil amendment and fertilization practices. Acidification by these processes can be controlled by normal soil management practices. However, large areas of the United States are not cultivated and have soils that are poorly buffered and therefore susceptible to further acidification. Many of these soils occur in forest and wilderness areas.

Significant quantities of plant nutrients, including N and S, are being added to soil in dry deposition and in precipitation. In some ecosystems these inputs may be important in the overall nutrient budget.

Various specific biological effects of simulated acid rain have been demonstrated in controlled field and laboratory experiments, but reliable evidence of economic damage to agricultural crops, forest and other natural vegetation, and to biological processes in soil by naturally occurring precipitation, dry deposition of aerosols, particulate matter, or interactions among these variables has been reported only rarely. A notable exception is the case of "russetting" of yellow delicious apples in orchards in New York, Nova Scotia, and North Carolina.

## Summary

It is obvious that a great deal of scientific research and both public and scientific discussion remains to be accomplished. This Action Seminar on Acid Precipitation has done much to stimulate increased public awareness of this important phenomenon. The next major scientific forum for discussion of these issues will be the International Symposium on Acid Precipitation to be held in Norway in March 1980. Continuing scientific dialogue, such as that between the Canadian-United States Consultative Group on Long Range Transport of Air Pollutants and the International Joint Commission will help to speed the day when the magnitude and importance of transboundary flux of air pollutants in North America will be better understood and be brought under better management. The Presidential Initiative on Acid Precipitation, and recent Congressional interest in acid precipitation research, provide a basis for increasing hope that the United States will do its part, together with Canada and other nations, to meet the challenge of continuing economic development with adequate safeguards for the quality of life and the long term productivity of ecosystems on which our good life so critically depends.

Let's get on with the job!

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